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FINAL REPORT

MAGNETOMETER SENSOR DEVELOPMENT PROGRAM

National Aeronautics and Space Administration
Ames Research Center
Moffett Field, California

December 1964

Prepared under Contract No. NAS 2-2070 by Honeywell Radiation Center, Boston, Massachusetts.

MAGNETOMETER SENSOR DEVELOPMENT PROGRAM

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National Aeronautics and Space Agency, Ames Research Center

Contract NAS 2-2070

The Magnetometer Sensor Development Program was conducted by Honeywell's Radiation Center in Boston under Contract NAS 2-2070 for NASA's Ames Research Center, Moffett Field, California. The objective of this seven-month study was to improve the Honeywell fluxgate sensor in areas of sensor material and second harmonic feedthrough. This final report summarizes the work accomplished on the contract and the results achieved.

The major accomplishments on the contract are listed below:

1. A specification for material with acceptable low noise characteristics for use on space flight fluxgate magnetometer sensors was arranged with Arnold Engineering Company.

2. A method of reducing second harmonic feedthrough on Honeywell type fluxgate sensors was developed.

3. Fluxgate Magnetometer Sensor, Honeywell type DLK6A1, was fabricated, tested and shipped to NASA, Ames.

4. It was shown that winding the sensor magnetic material on the sensor bobbin after final annealing does not degrade its noise characteristics. This fact shows that annealing after manufacture is not necessary.

5. The size of the magnetic material used in Honeywell fluxgate sensors was optimized at 1/16" wide x 1/8 mil thick.

The contract was broken into three separate tasks which were:

1. Investigation of Fluxgate Sensor Core Materials and Annealing.

2. Fluxgate Sensor Second Harmonic Feedthrough Improvement.

3. Deliver an Improved Fluxgate Sensor to Ames.

INVESTIGATION OF FLUXGATE SENSOR CORE MATERIALS AND ANNEALING

Honeywell worked with the Naval Ordnance Laboratory, White Oak, Maryland in an attempt to define an annealing process that would produce satisfactory material for use in low noise fluxgate sensors. Based on previous experience as well as considering the limited time available, 4-79 Mo-Permalloy was chosen as the material to be used in fluxgate sensors. Therefore, annealing experiments conducted with NOL were limited to 4-79 Mo-Permalloy. Twelve samples of material were annealed by NOL for evaluation by Honeywell. All of these samples proved unsatisfactory having 0-10 cps noise ranging from 0. 6 gamma to as high as several gamma. The material samples were annealed to obtain various degrees of squareness and high initial permeability. The test results obtained with NOL samples showed that an annealing process could not be developed within the time limit and dollar value of this contract.

Various samples of 4-79 Mo-Permalloy purchased from the Arnold Engineering Company of Marengo, Illinois, had previously produced satisfactory sensors having 0-10 cps bandwidth noise of 0. 2 to 0. 3 gamma. An engineering conference between Honeywell and Arnold was arranged to write purchase specifications for various sizes of annealed and unannealed sensor material. Specifications were also written for annealing of bobbins wrapped at Honeywell. These purchase specifications were based on processes used by Arnold on previous Honeywell orders that resulted in material being satisfactory for use in fluxgate sensors. The information contained in the Arnold drawings are included in this report as Figures 1 through 6.

An experiment was conducted to determine if any detrimental effects to sensor noise characteristics were caused by wrapping the Mo-Permalloy on the bobbin after it had been annealed. Five bobbins were wrapped with unannealed Mo-Permalloy (Arnold Part 18184) and sent to Arnold Engineering for annealing as described in Arnold Drawing A18186. The noise characteristics of these bobbins are shown in Figures 7 through 11.

The noise characteristics of these five bobbins are very close to the noise characteristics obtained by wrapping after annealing (approximately 0. 20 gamma to 0. 25 gamma 0-10 cps bandwidth) using Arnold material 18182. Therefore, it may be concluded that a post anneal wrap as is presently being performed at Honeywell does not damage the metal. This conclusion is further supported by the uniform noise characteristics obtained on sensors made from the same roll of 4-79 Mo-Permalloy. If strain was being set up in the Mo-Permalloy it would be random, therefore each sensor would have a different noise characteristic.

A sensor was made using 24 wraps of 1/32" x 1/8 mil material (Arnold Part 18183). The noise characteristics of this sensor (approximately 0.35 gamma 0-10 cps bandwidth) are shown in Figure 12. This noise is higher than that obtained with sensors using three wraps of 1/16" wide x 1/2 mil thick material on the sensor core. In addition, the 1/32" x 1/8 mil material is very difficult to work with as it has a tendency to curl and twist. Based on these facts, sensor material size was optimized at 1/16" wide x 1/8 mil thick.

Summary of Material Studies

Arnold Engineering Company Part 18182 (4-79 Mo-Permalloy) is satisfactory material for use in fluxgate magnetometer sensors. This material will yield sensors having 0-10 cps bandwidth peak to peak noise characteristics of from 0.15 gamma to 0.35 gamma.

FLUXGATE SENSOR DRIVE SECOND HARMONIC FEEDTHROUGH IMPROVEMENT

Second harmonic feedthrough is defined as the amount of second harmonic sensor output caused by second harmonic distortion in the excitation voltage. Tests have shown that second harmonic feedthrough increases proportionally with increases in excitation second harmonic distortion. It is felt that the feedthrough exhibited by Honeywell fluxgate sensors is caused in large part by non-homogeneity of the Mo-Permalloy. This will cause a slight amount of imbalance in the drive circuit. This imbalance may be corrected by the addition of small amounts of metal on one side or the other of the drive circuit. This method is quite time consuming and impractical since it is a trial-and-error approach and requires complete reworking of the drive winding for each trial. Therefore, it was decided to cancel the effects of 10 kc feedthrough by producing a voltage approximately equal to the feedthrough voltage and connected to the output in phase opposition to the feedthrough voltage.

The feedthrough cancellation voltage is produced by the addition of a winding consisting of up to 30 turns of wire on each sector of the drive winding. The drive winding size was reduced in order that the feedthrough cancellation winding could be added to the sensor without increasing sensor size. The feedthrough cancellation winding contains both 5 kc and 10 kc reflected from the drive voltage and is connected in series with the output winding. The phase relation between the 10 kc caused by feedthrough and the 10 kc in the feedthrough cancellation winding is such that no phase shift networks are necessary to produce feedthrough cancellation.

The feedthrough cancellation winding provides the following to the fluxgate sensor:

1. The feedthrough cancellation is proportional to the amount of distortion in the excitation voltage. Therefore, as excitation distortion increases feedthrough cancellation increases.

2. The feedthrough cancellation is not sensitive to temperature since no phase shifting circuits are involved.

3. The feedthrough cancellation winding will tend to cancel any output noise caused by the excitation voltage.

4. The phase relation between the 5 kc output of the feedthrough cancellation winding and the 5 kc peaks of the raw null is such that peak to peak sensor null is substantially reduced.

The feedthrough cancellation winding is trimmed for each fluxgate sensor to obtain the best combination of feedthrough and peak to peak null and is discarded when not required. Sensors requiring more than thirty (30) turns to reduce feedthrough to satisfactory levels are rejected and reworked.

IMPROVED FLUXGATE SENSOR

A fluxgate sensor reflecting the improvements listed above was shipped to NASA-Ames. Complete test data was shipped with the sensor which was given the Honeywell model number DLK6A1. Copies of the Honeywell Installation Drawing, DLK6A1, are enclosed with this report.

FUTURE IMPROVEMENT PROGRAMS

Although this program produced a satisfactory method of specifying sensor material, it did not disclose the cause of sensor noise. Future programs are recommended to provide detailed noise analysis, possibly in conjunction with a cryogenic magnetic shield. Additional methods of improving S/N characteristics of fluxgate sensors including variations of drive frequency and continued materials studies should also be pursued.

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David E. Ratcliff

David E. Ratcliff
Program Manager

jk

SPECIFICATION

The Arnold Engineering Company - A18182

1. Anneal stainless steel bobbin TG-6696 (for 1/16" wide tape) in hydrogen for two hours at 2000°F.

2. Wind required footage (up to 70 feet) of methylate coated 1/16" x 1/2 mil 4-79 Mo-Permalloy tape on bobbin. Must be Heat "A". Weld outer wrap.

3. Anneal using Tape Annealing Procedure Number 11.

4. Tag annealed bobbin and tape with A. E. Co. part number 18182 and number of feet of tape on bobbin.

REF: K18182-P500-EA

Figure 1

SPECIFICATION

The Arnold Engineering Company - A18183

1. Anneal stainless steel bobbin TG-6696 (for 1/32" wide tape) in hydrogen for two hours at 2000°F.

2. Wind required footage (up to 250 feet) of methylate coated 1/32" x 1/8 mil 4-79 Mo-Permalloy tape on bobbin. Must be Heat "A". Weld outer wrap.

3. Anneal using Tape Annealing Procedure Number 11.

4. Tag with A. E. Co. part number 18183 and number of feet of tape on bobbin.

<u>REF: K18183-P125</u>

Figure 2

SPECIFICATION

The Arnold Engineering Company - A18184

1. Using stainless steel bobbin TG-6696 (for 1/16" wide tape) wind required footage (up to 70 feet) of methylate coated 1/16" x 1/2 mil 4-79 Mo-Permalloy tape. Must be from Heat "A". Fasten outer wrap with mylar tape.

2. Tag bobbin and tape with A.E.Co. part number 18184. Ship unannealed.

REF: K18184-P500-EA

Figure 3

SPECIFICATION

The Arnold Engineering Company - A18185

1. Using stainless steel bobbin TG-6696 (for 1/32" wide tape) wind required footage (up to 250 feet) of methylate coated 1/32" x 1/8 mil 4-79 Mo-Permalloy tape. Must be from Heat "A". Fasten outer wrap with mylar tape.

2. Tag bobbin and tape with A.E.Co. part number 18185. Ship unannealed.

REF: K18185-P500-125-EA

Figure 4

SPECIFICATION

The Arnold Engineering Company - A18186

1. This drawing covers annealing of customer supplied tape wound bobbins. Bobbins will be supplied wound with 1/16" x 1/2 mil 4-79 Mo-Permalloy, Heat "A". The outer wrap will be held in place by tape. The wound bobbin shall be supplied in protective box or jacket so that annealed unit can be returned in same protective package to minimize impairment of annealed magnetic properties.

2. Upon receipt of wound bobbins remove tape holding outer wrap and weld wrap in place.

3. Anneal per Tape Annealing Procedure No. 11.

4. Place in protective package supplied by customer and wrap in Chem-pak for shipment. CAUTION: Annealed bobbin must be handled such that the tape is not strained.

REF: K18186-P500-EA

Figure 5

SPECIFICATION

The Arnold Engineering Company - A18187

1. This drawing covers annealing of customer supplied tape wound bobbins. Bobbins will be supplied wound with 1/32" x 1/8 mil 4-79 Mo-Permalloy, Heat "A". The outer wrap will be held in place by tape. The wound bobbin shall be supplied in protective box or jacket so that annealed unit can be returned in same protective package to minimize impairment of annealed magnetic properties.

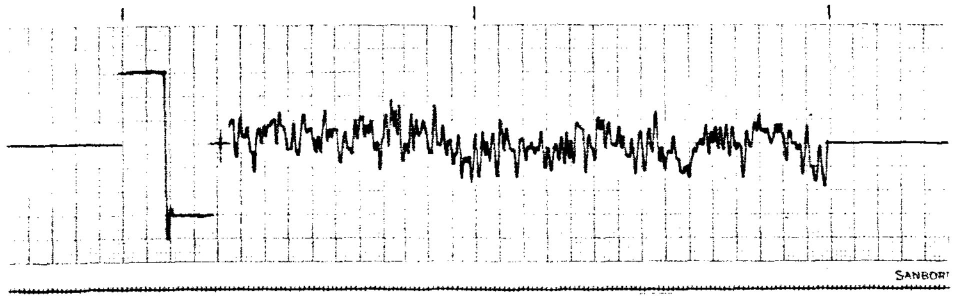
2. Upon receipt of wound bobbins remove tape holding outer wrap and weld wrap in place.

3. Anneal per Tape Annealing Procedure No. 11.

4. Place in protective package supplied by customer and wrap in Chem-pak for shipment. CAUTION: Annealed bobbin must be handled such that the tape is not strained.

REF: K18187-P125

Figure 6



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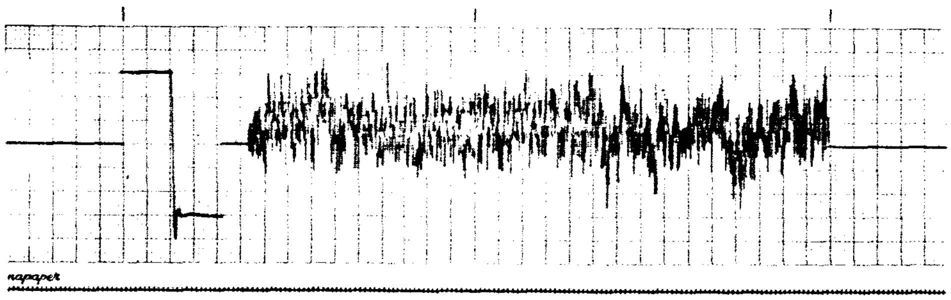

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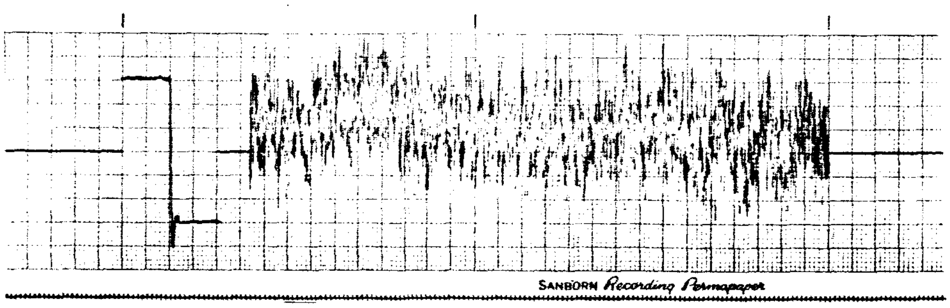
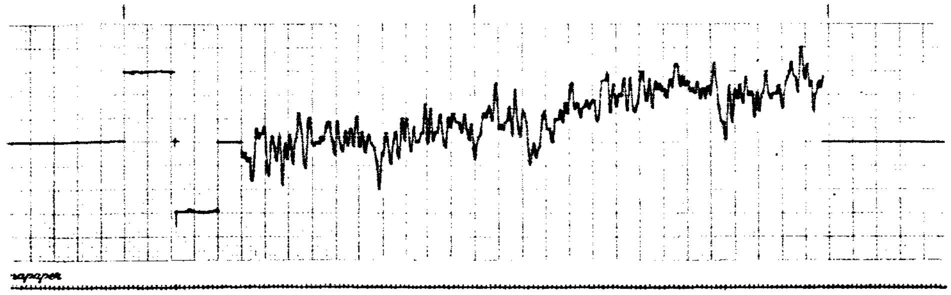


Filter Cutoff Frequency - 10 cps

Honeywell Drive Winding #280
Honeywell Output Winding #137
Excitation Voltage - 1.41 VRMS
Excitation Current - 178 ma p-p
Calibration - $\pm 0.15\gamma$

Special Conditions: Material annealed after wrap by Arnold Engineering Co.

Figure 7



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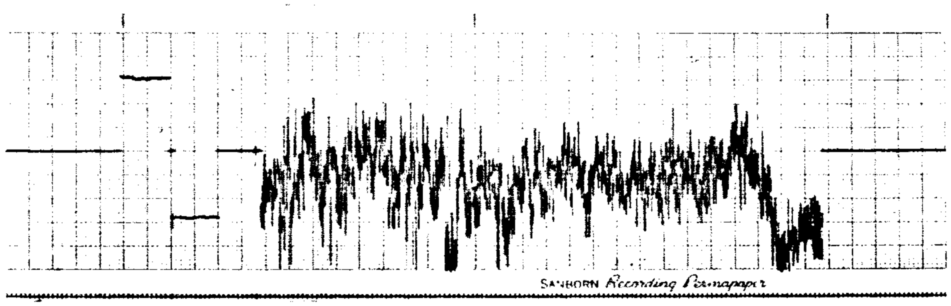

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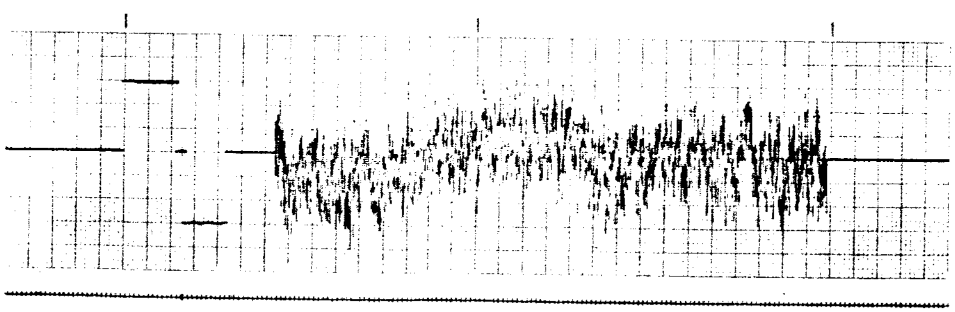

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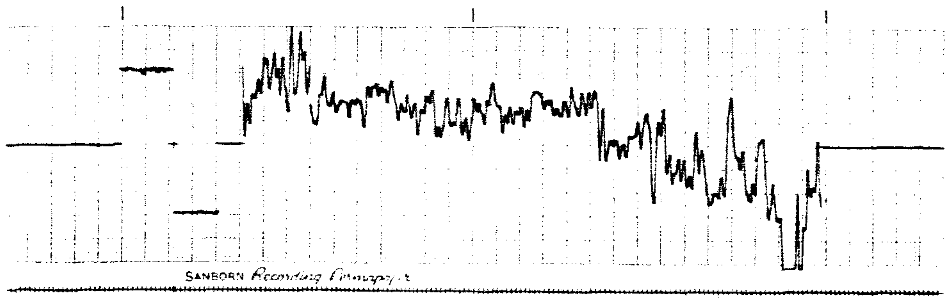
Honeywell Drive Winding #281
Honeywell Output Winding #137
Excitation Voltage - 1.41 VRMS
Excitation Current - 176 ma p-p
Calibration - $\pm 0.15\ \gamma$
Special Conditions: Material annealed after wrap by Arnold Engineering Co.

Figure 8



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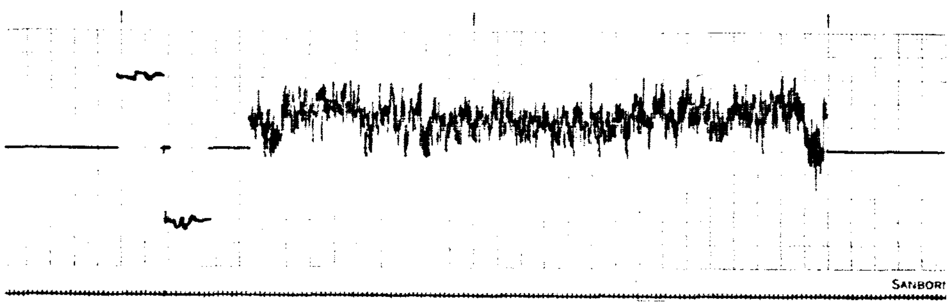

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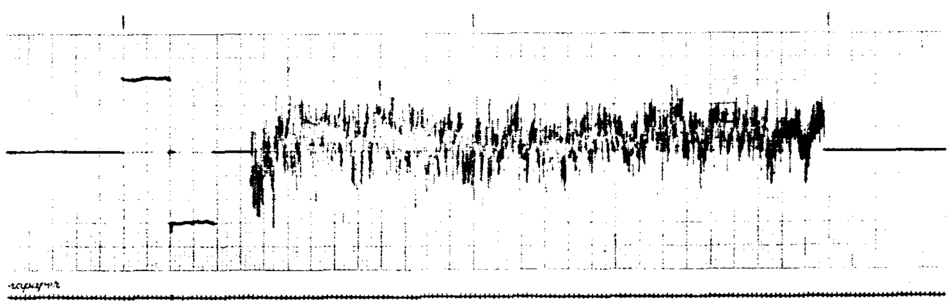
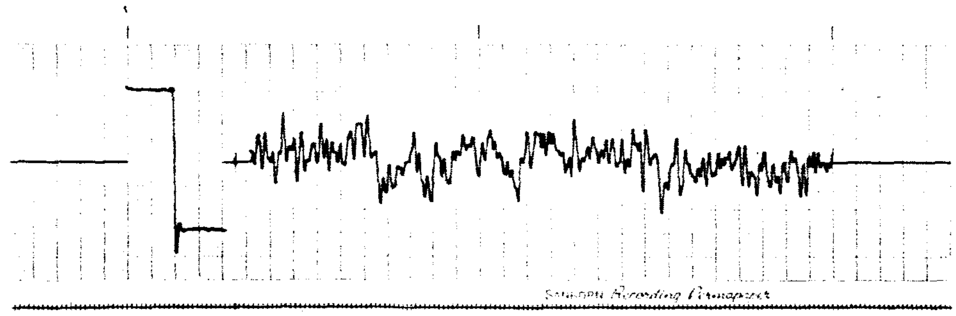


Filter Cutoff Frequency - 10 cps

Honeywell Drive Winding #282
Honeywell Output Winding #137
Excitation Voltage - 1.41 VRMS
Excitation Current - 176 ma p-p
Calibration - $\pm 0.15\gamma$
Special Conditons: Material annealed
after wrap by Arnold Engineering Co.

Figure 9



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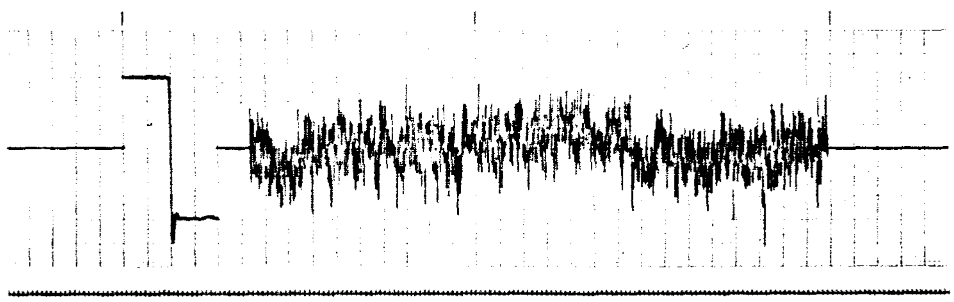

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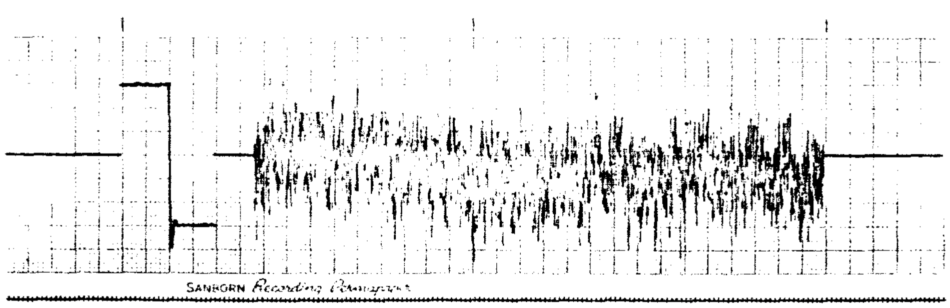
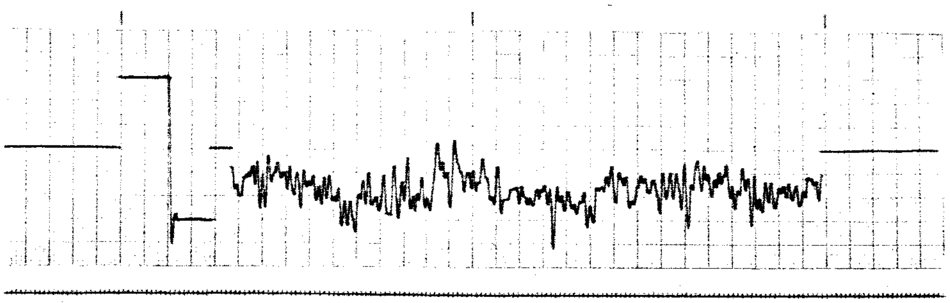


Filter Cutoff Frequency - 10 cps

Honeywell Drive Winding #283
Honeywell Output Winding #137
Excitation Voltage - 1.41 VRMS
Excitation Current - 180 ma p-p
Calibration - $\pm 0.15\gamma$
Special Conditions: Material annealed after wrap by Arnold Engineering Co.

Figure 10



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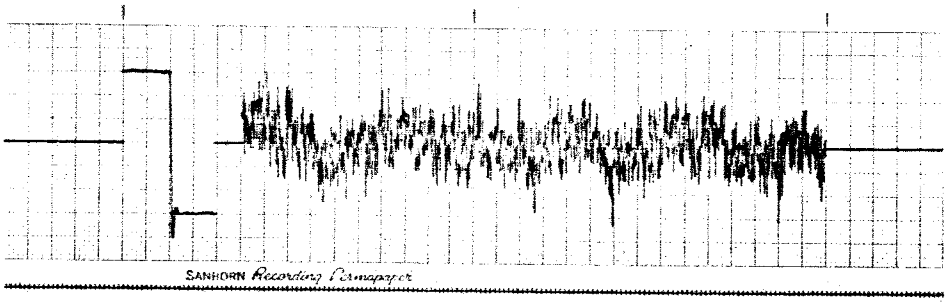

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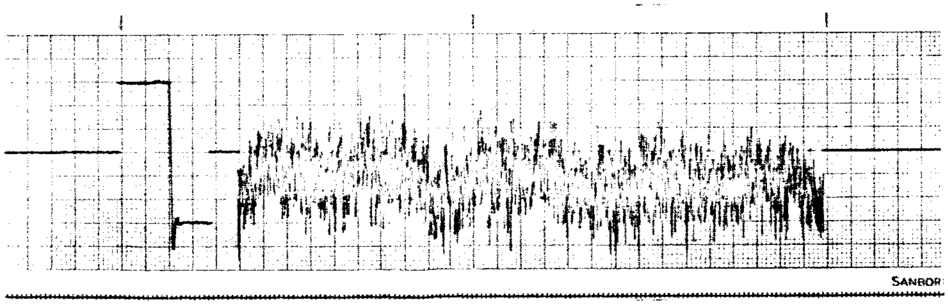
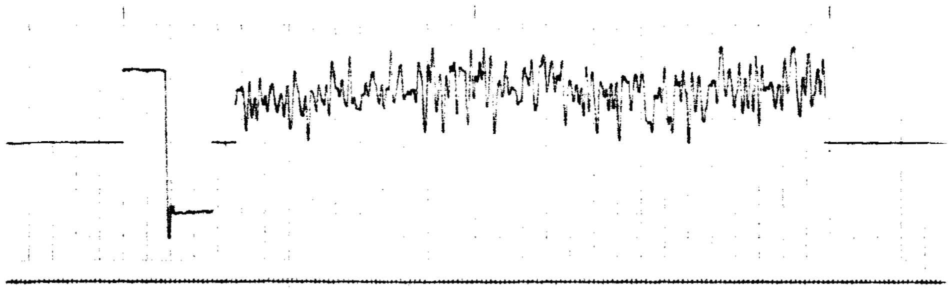


Filter Cutoff Frequency - 10 cps

Honeywell Drive Winding #284
Honeywell Output Winding #137
Excitation Voltage - 1.41 VRMS
Excitation Current - 172 ma p-p
Calibration - $\pm 0.15\gamma$
Special Conditions: Material annealed after wrap by Arnold Engineering Co.

Figure 11



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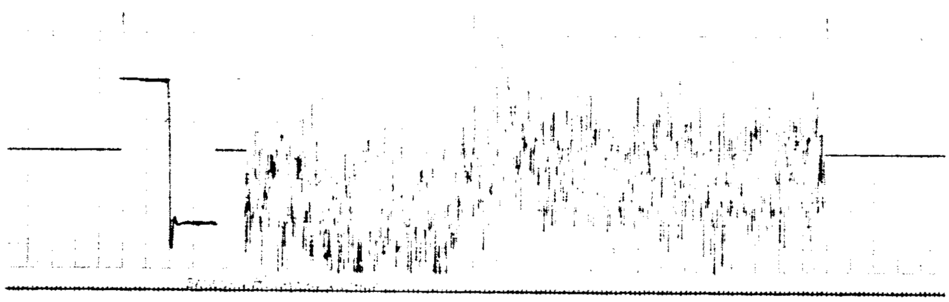

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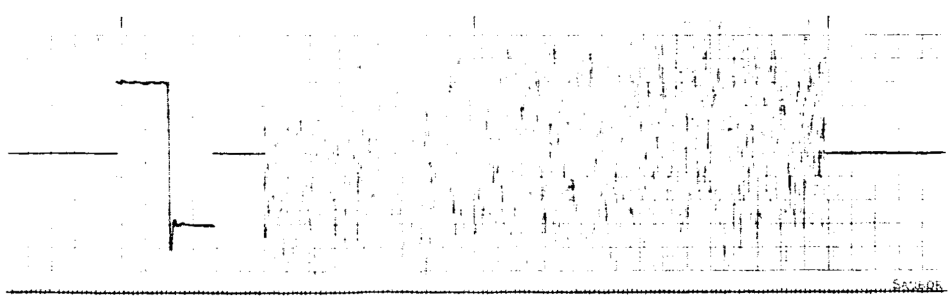

Filter Cutoff Frequency - 10 cps

Honeywell Drive Winding #278
Honeywell Output Winding #137
Excitation Voltage - 1.41 VRMS
Excitation Current - 174 ma p-p
Calibration - $\pm 0.15\gamma$
Special Conditions: 24 wraps 1/32" wide
x 1/8 mil 4-79 Mo-Permalloy

Figure 12